Spin Reorientation Transition in Fe-Rich Alloy Films on W(110): The Role of Magnetoelastic Anisotropy and Structural Transition

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Epitaxial Fe-rich alloy films of formula $Fe_{1-x}Ni_x$, $Fe_{1-x}Co_x$, and $Fe_{1-x}V_x$ were grown on a W(110) substrate with a bcc structure without any structural transition at $x < 0.3$. Using chemical pressure (inserting small amounts of Ni, Co, or V into Fe), we controlled the lattice constant of these alloy films and then measured the variation of spin reorientation thickness (t_r) according to the alloy composition. We focused on the roles of lattice constant of the film and the spin reorientation thickness that is closely related to the strain associated with the lattice mismatch between the thin film and the substrate.

The magnetic anisotropy of a film is a key parameter determining its easy and hard magnetization axes, and hence is a very important determinant of the film's magnetic properties such as the spin reorientation transition (SRT), which is decided by competition between volume anisotropy term (K^V) and interface anisotropy contribution term (K^{int}). The simple equation for SRT can be expressed as $K^{eff} = K^V + K^{int}/t$ (when $K^{eff} = 0$, we can determine t_r.)

In magnetic systems with a large lattice mismatch (e.g., Fe on W(110), mismatch ~10.1 %), however, it is necessary to also consider the magnetoelastic anisotropy (K_{me}). If, the K_{me} strongly influences the SRT, we can control the transition by modifying the lattice constant using chemical pressure as we make alloy film with different lattice constants. Also, one of the most interesting issues in thin alloy films is the correlation between the magnetic properties and structural transitions as a function of alloy composition. Here, we investigate that the lattice constant of the film and the spin reorientation thickness (t_r) play key roles in determining the location of the SRT as the alloy composition is varied using SRPES and LEED.

Figure 1 displays LEED images for three alloy systems ($Fe_{1-x}Ni_x$, $Fe_{1-x}Co_x$, and $Fe_{1-x}V_x$) as a function of alloy composition. In the case of the $Fe_{1-x}Ni_x$ film, the distance between the spots in the W(110) and Fe-rich alloy is being decreased with increasing Ni concentration. It indicates that the lattice mismatch diminishes as Ni is added to the Fe; specifically, the mismatch decreases from 7.4 % to 5.5 % when x is increased from 0.1 to 0.2. In terms of the real spacing, the data show that increasing the Ni concentration expands the Fe lattice, thereby increasing the lattice constant. We also used a similar approach to measure the variation of lattice mismatch for $Fe_{1-x}Co_x$, and $Fe_{1-x}V_x$ alloy films. We found that Co and V also expand the Fe lattice, although to a lesser extent

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than Ni: for the $Fe_{1-x}Co_x$ alloy film, the mismatch decreased from 9.1 % to 6.5 % when x was increased from 0.1 to 0.3; and for the $Fe_{1-x}V_x$ alloy film, the mismatch decreased from 9.6 % to 9.2 % when x was increased from 0.1 to 0.3. Thus, we can precisely control the lattice constant of these alloy films by modifying the alloy composition in the Fe-rich region (bcc structure). Using this *chemical pressure* approach, we monitored the change of t_r as a function of alloy composition using SRPES.

Figure 2 shows typical results of spin resolved photoemission spectra and their asymmetry value between spin up and spin down spectra, for the change of t_r as monitored with SRPES for three alloy systems at $x = 0.1$. On a W(110) substrate, we grew Fe-rich alloy wedge films with thicknesses spanning a range (in increments of 4 Å) that encompassed the SRT from $[1\bar{1}0]$ to $[001]$. SRP spectra were then recorded as a function of the film thickness along this wedge (z-axis). The SRP spectra and asymmetry results show that the thinner films (bottom spectra) are magnetized along the $[1\bar{1}0]$ direction, whereas the thicker films (top spectra) are magnetized along the [001] direction.[15] As shown in

these spectra, we can clearly see that t_r varies widely depending on the alloy used, exhibiting values of 326 Å for $Fe_{0.9}Ni_{0.1}$, 102 Å for $Fe_{0.9}Co_{0.1}$, and 76 Å for $Fe_{0.9}V_{0.1}$. These results indicate that insertion of Ni or Co dramatically increases t_r relative to that of the pure Fe film (85 Å),[15] whereas insertion of V decreases it slightly.

In summary, we found that alloys of formula $Fe_{1-x}M_x$ (M = Ni or Co) exhibit a pronounced increase in t_r with increasing x, with the effect being larger in Fe-based alloys. We found that the change of lattice mismatch (strain effect) and structural transition (from *bcc* to *fcc* or *fct*) in these systems play key roles in the observed increase in t_r. Contrary to the behavior of Ni and Co, insertion of increasing amounts of V into the Fe lattice causes t_r to decrease, which we speculate is due to an order-to-disorder transition.
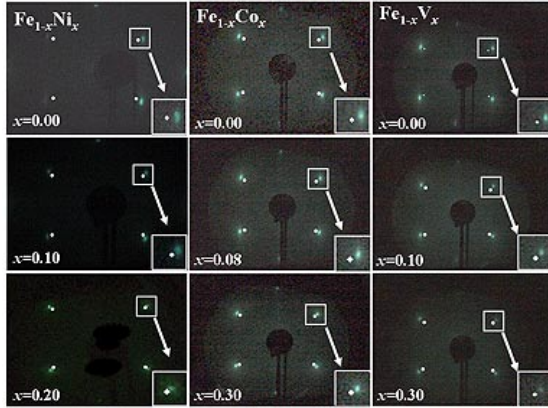
Figure 1. LEED images for three different alloy systems (left panels are $Fe_{1-x}Ni_x$, middle panels are $Fe_{1-x}Co_x$, and right panels are $Fe_{1-x}V_x$) as a function of alloy composition. All LEED images show a bcc structure. The inset image of each LEED data indicates magnified spots between alloy film and W(110) substrate to show clearly the variation of distance between two spots.
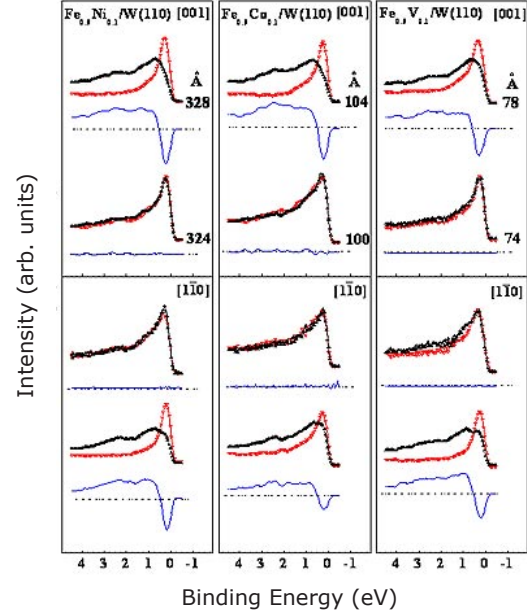
Figure 2. Typical result for magnetic reorientation transition as monitored with spin-resolved photoemission spectra of (a : $Fe_{1-x}Ni_x$), (b: $Fe_{1-x}Co_x$), and (c: $Fe_{1-x}V_x$) at x = 0.1 concentration. The spectra were measured at 40 eV in normal emission. Each filled up-triangles and empty down-triangles represent majority- and minority- spin components, respectively. Below each spin resolved photoemission spectra, asymmetry values $(I_{spin\ up} - I_{spin\ down})/(I_{spin\ up} - I_{spin\ down})$ also are displayed to show a clear change for spin reorientation for three alloy films. $I_{spin\ up}$ and $I_{spin\ down}$ indicate the intensity of majority spin and minority spin, respectively.